Morphological Characterization of Isolated Wetland Depressions in the Des Moines Lobe of Iowa

(And Their Potential Influence on Downstream Waters)

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EPA Region 7

Iowa State University

Bio

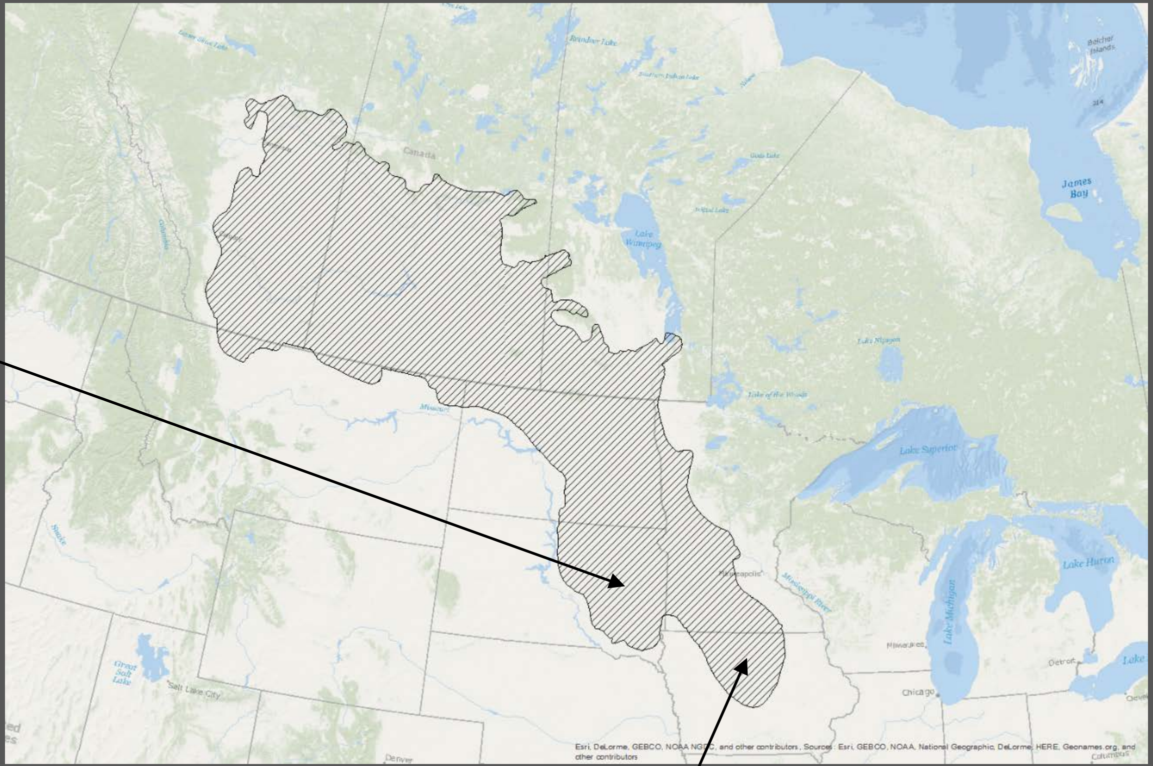
Myself

- B.S. Environmental Science (Hydrology Focus)/Chemistry (Environmental Focus), University of New Mexico (2003).
- Hydrologist New Mexico Interstate Stream Commission (2004 – 2007).
- Ph.D. Environmental Science (Hydrology and Hydrodynamics Focus), Iowa State University (2016).
- Post-doc Wetlands Research Laboratory, Iowa State University.

Sam McDeid (Very talented GIS/Python programmer).

- B.S. Environmental Science, Iowa State University (2014).
- M.S. Environmental Science (Expected Summer 2017), Iowa State University.

Background



Highly altered landscape

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Restoration of ecosystem functions

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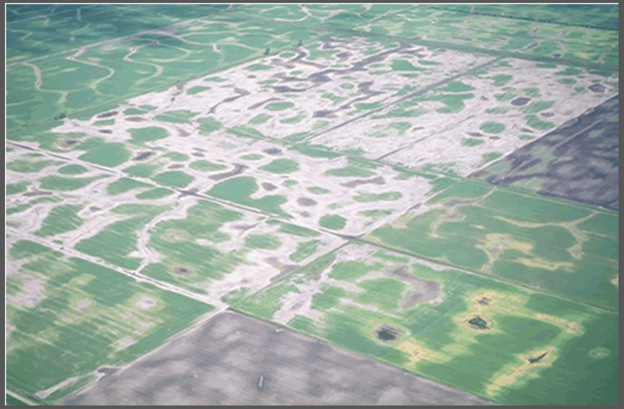
Restoration of pothole wetlands



Importance of Depressional Morphology

Restoration of ecosystem functions (Galatowitch and van der Valk, 1996)

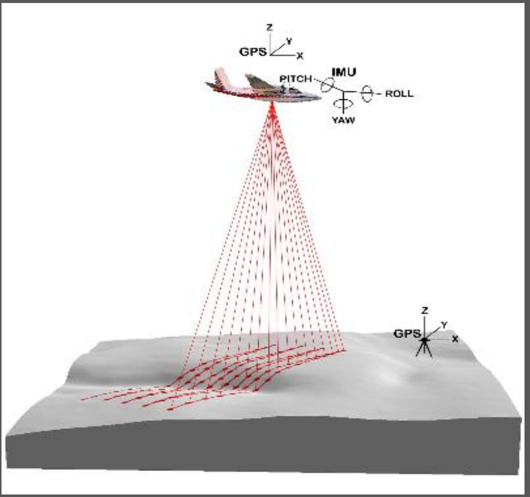
1. Guide or inform restoration of altered wetlands.
2. Morphology is critical for wetland seeding/plant growth.
3. Restoration of hydrological regimes.

Understanding the role of depressional storage on watershed and regional hydrology

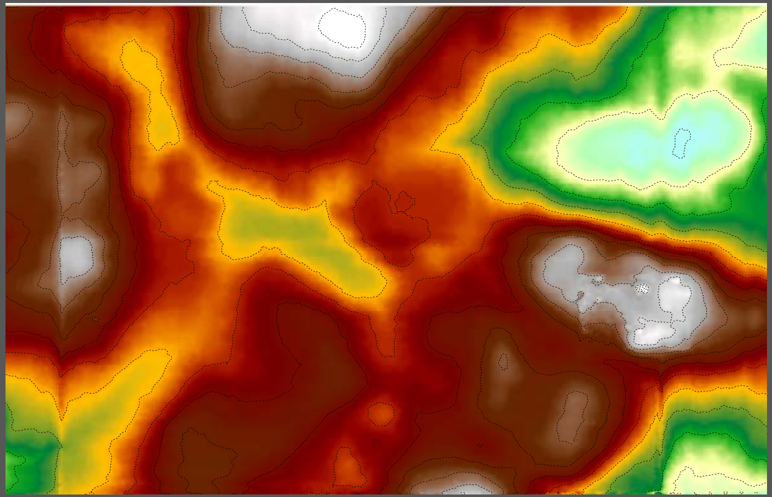
1. Flood mitigation impacts of depressions.
2. Determining flood storage capacity of depressional wetlands.
3. Dynamic modeling of rainfall runoff processes.
4. Depressional wetland connectivity.

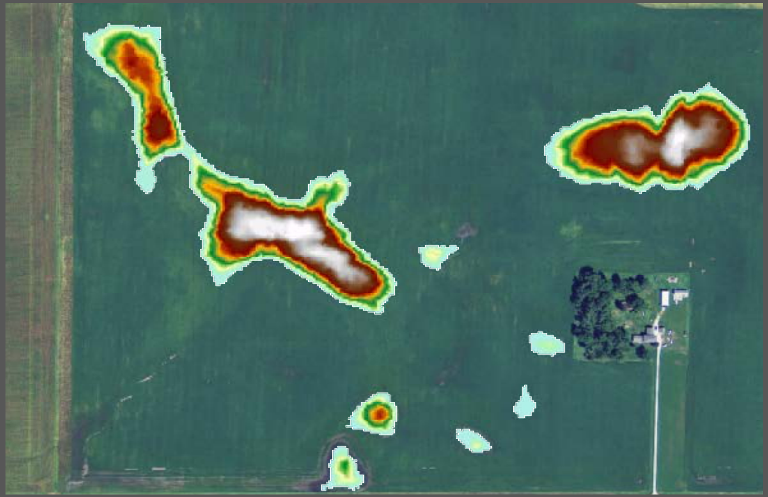
Existing Methodology: LiDAR

- Historically small geographic focus despite increasing prevalence (e.g. Wu and Lane, 2016).
- Allows for large-scale, high resolution, accurate topographic analyses.
- Faster and cheaper than manual surveying.



http://forsys.cfr.washington.edu/JFSP06/lidar_technology.htm

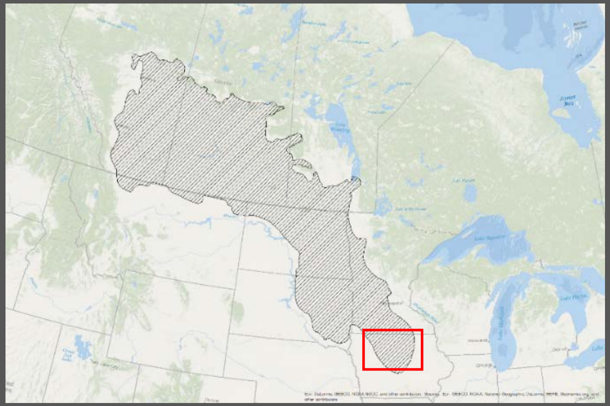


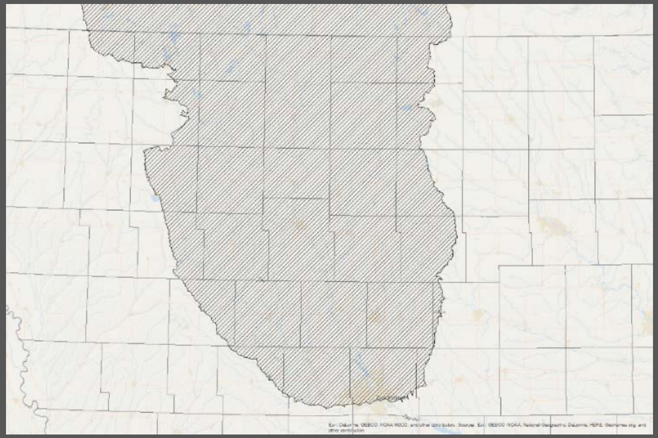


Project Overview

- US EPA Region 7 Wetland Program Development Grant (2015).
- Develop a toolset in Python/ArcGIS to assess the morphology of all depressions in an arbitrary geographic region given a DEM (arbitrary resolution).
- Use state-wide 3m hydrologically corrected LiDAR-derived DEMs and toolset to delineate morphology for all depressions in the DML in Iowa.
- Derive hypsographic curves for all depressions and statistically characterize bulk morphological properties.

Des Moines Lobe





Pre-settlement

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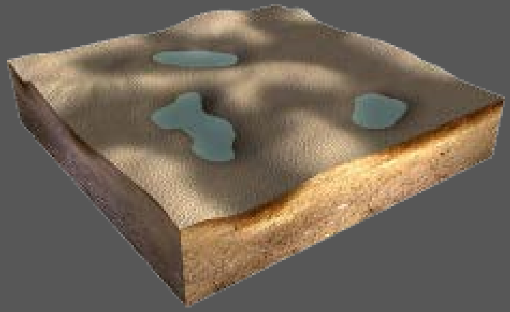
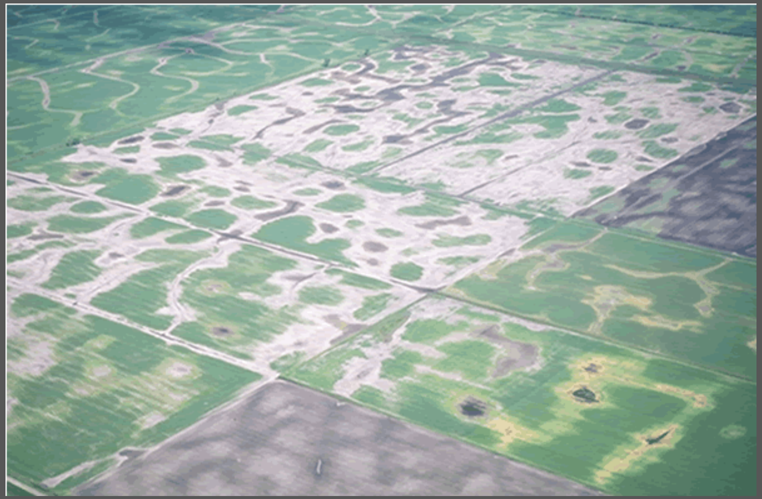


Post-settlement



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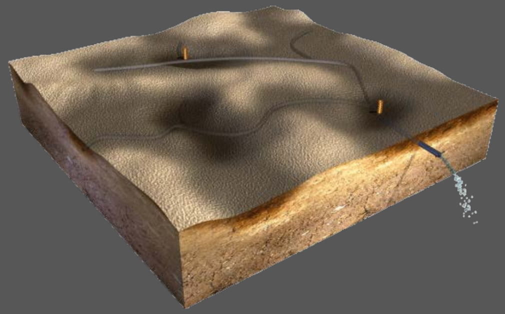
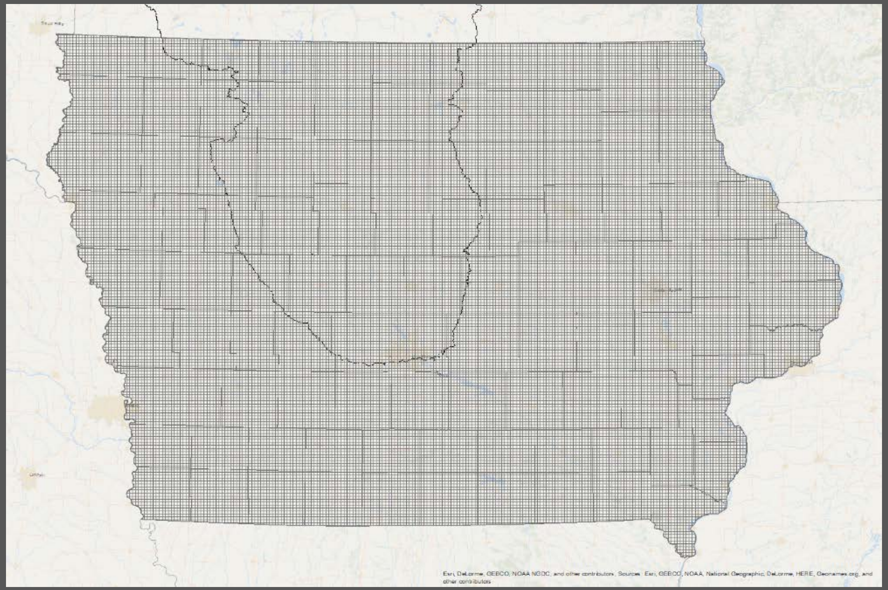


ISU Wetlands Research Lab

Subsurface Tile Drainage

Des Moines Lobe

State-wide LiDAR flown in 2007 → Bare earth → Hydrologically enforced (Gelder, 2013)

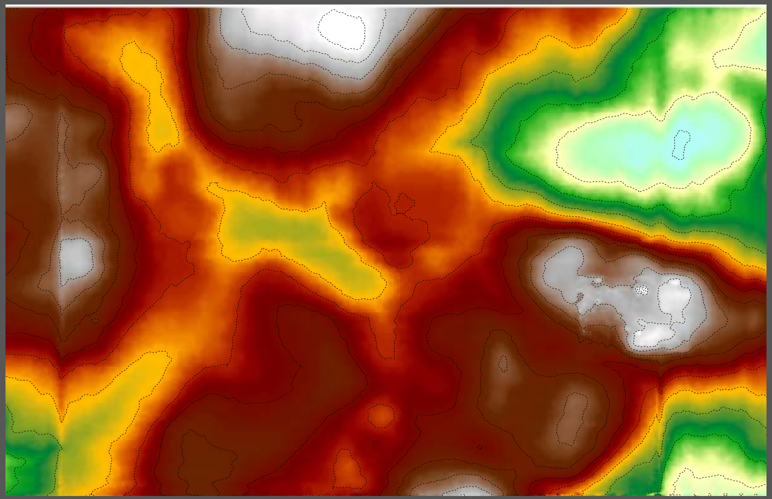


Iowa LiDAR Coverage

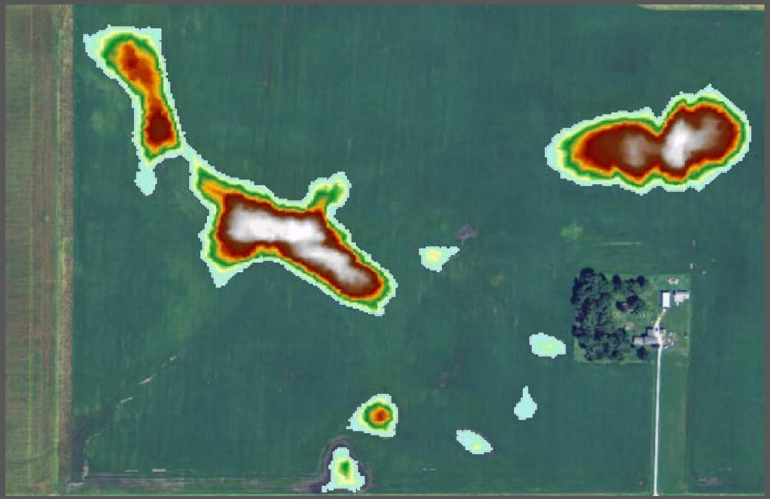
Example 3m LiDAR-derived DEM

Drainage of depressions means LiDAR can be used to evaluate depressional morphology

Algorithm



DEM Region

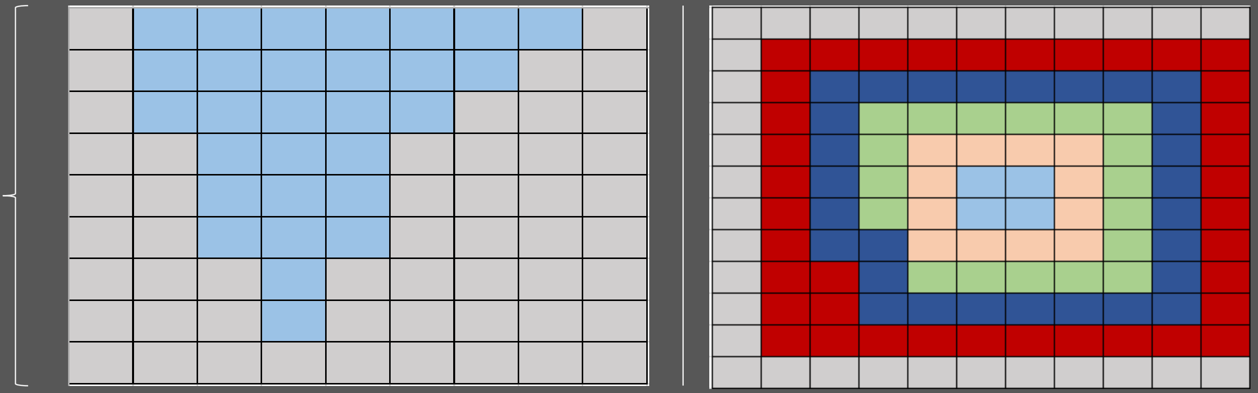


Sink Filling and Differencing

Identification and Region Grouping

COUNT	DEPTH	AREA	VOLUME
2	0.01	18	0.18
5	0.02	63	0.36
9	0.03	144	0.99
13	0.04	261	2.43
37	0.05	594	5.04
25	0.06	819	10.98
25	0.07	1044	19.17
31	0.08	1323	29.61
18	0.09	1485	42.84
35	0.1	1800	57.69
35	0.11	2115	75.69
43	0.12	2502	96.84
72	0.13	3150	121.86

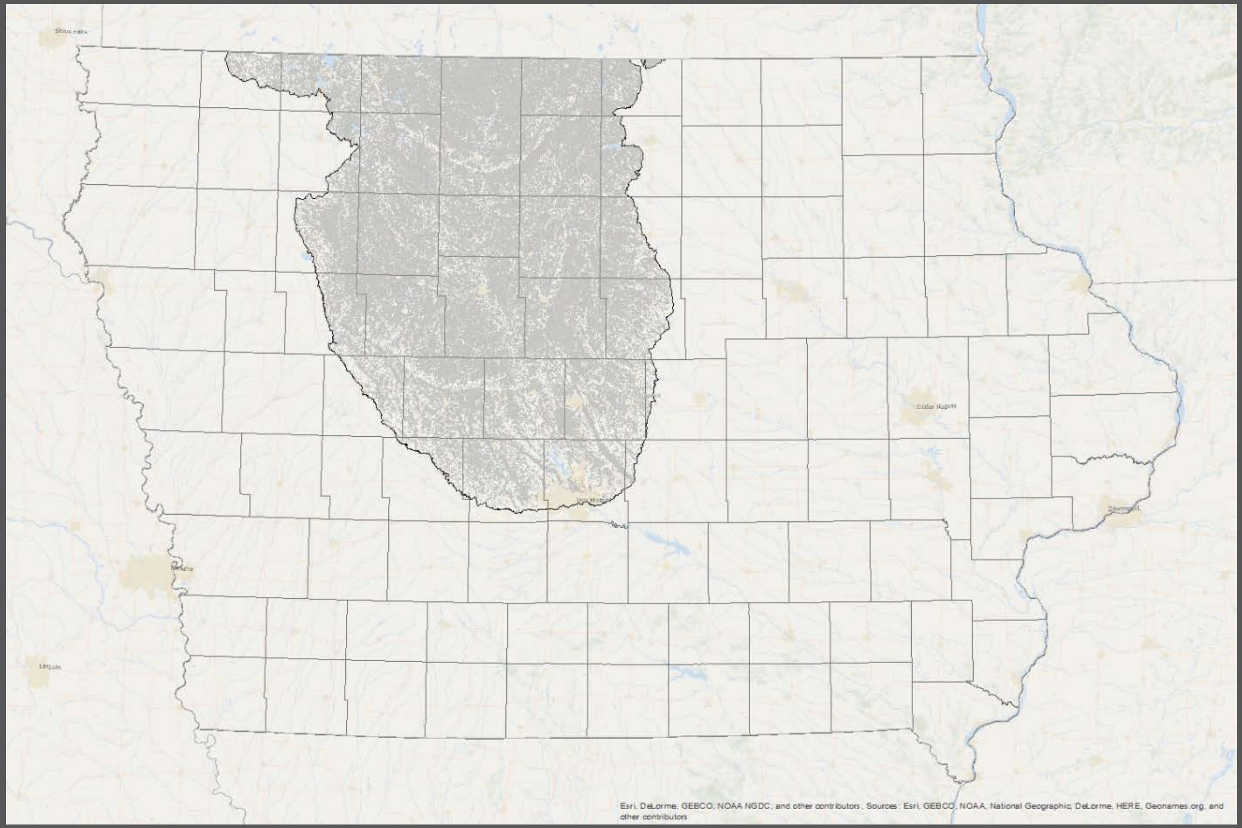
Hypsometric Table



The construction of the depth-area-volume table is performed through Reimann integration over the entire depression

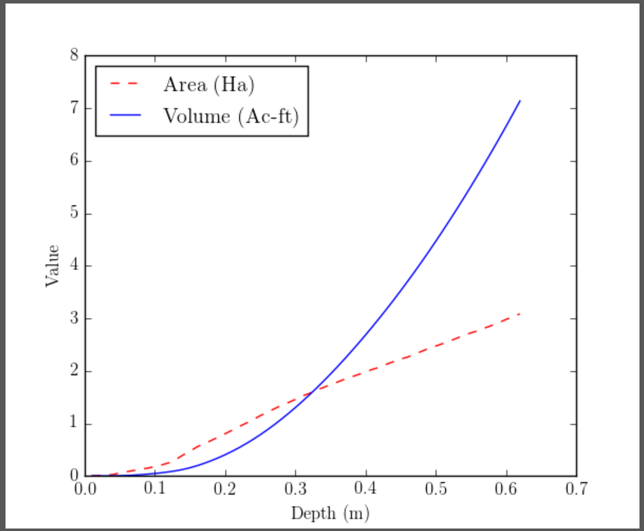
Results: Bulk Properties

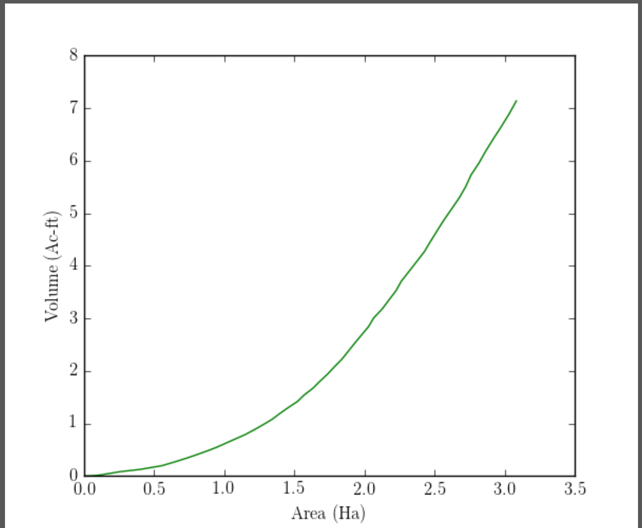
- 470,000 Depressions Identified.
- Total maximum area of inundation: 258,227 Hectares (8.3%).
- Total maximum storage volume: 787,000 Acre-feet (122% of Saylorville Reservoir Flood Storage).
- Maximum Area of Inundation (A_{max}): 0.01 – 591 Hectares.
- Maximum Inundation Volume: (V_{max}): 0.002 – 7449 Acre-feet.



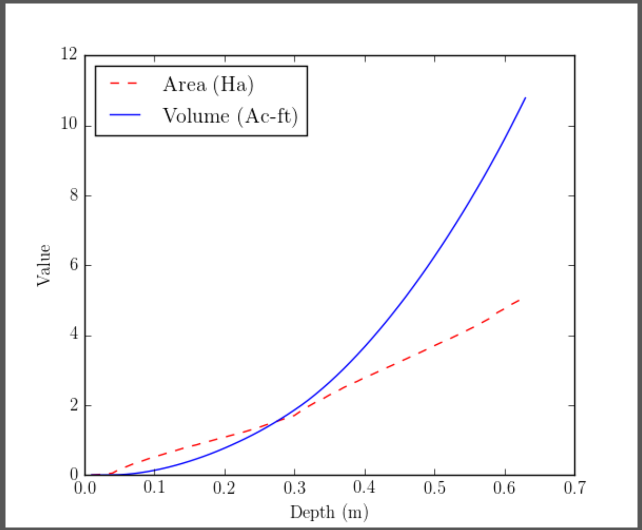
Results: Hypsography

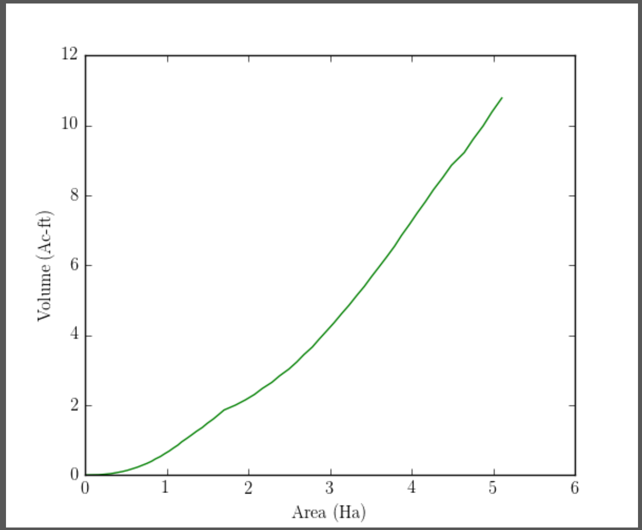
2010 Aerial Image (Region-wide Flood Conditions)





Hypsographic Curves





Hypsometric Table

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5	0.02	63	0.36
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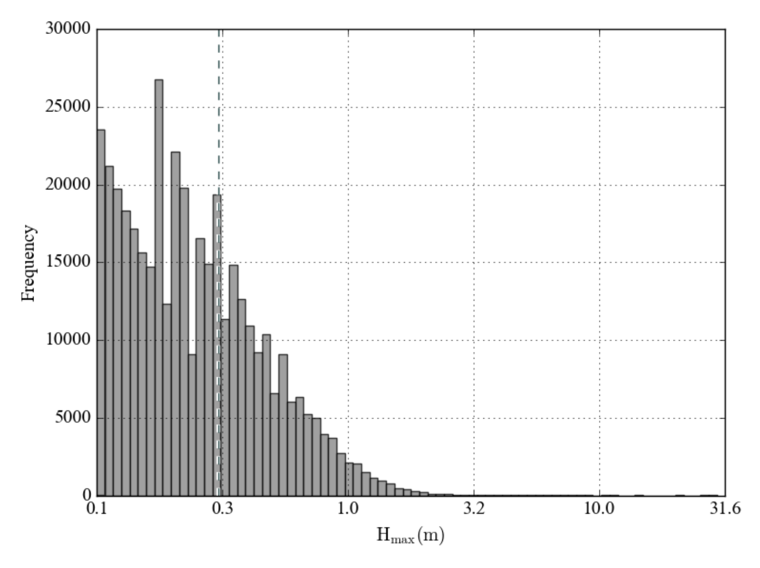
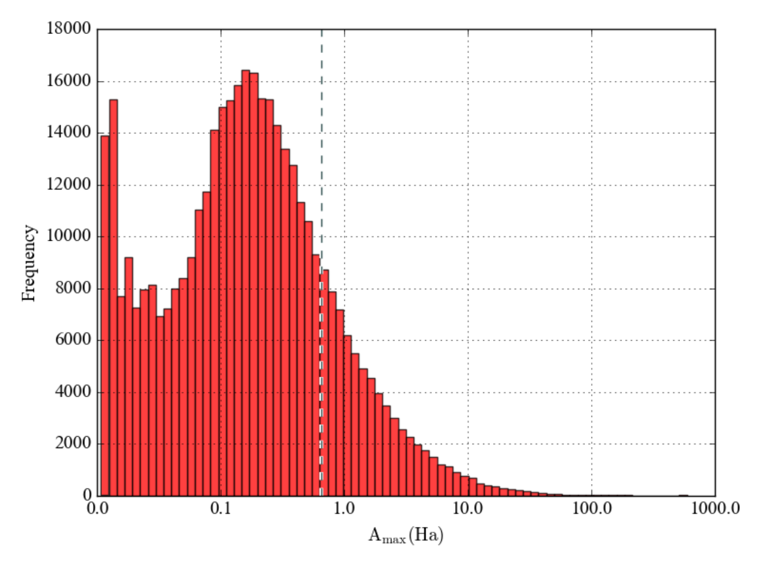
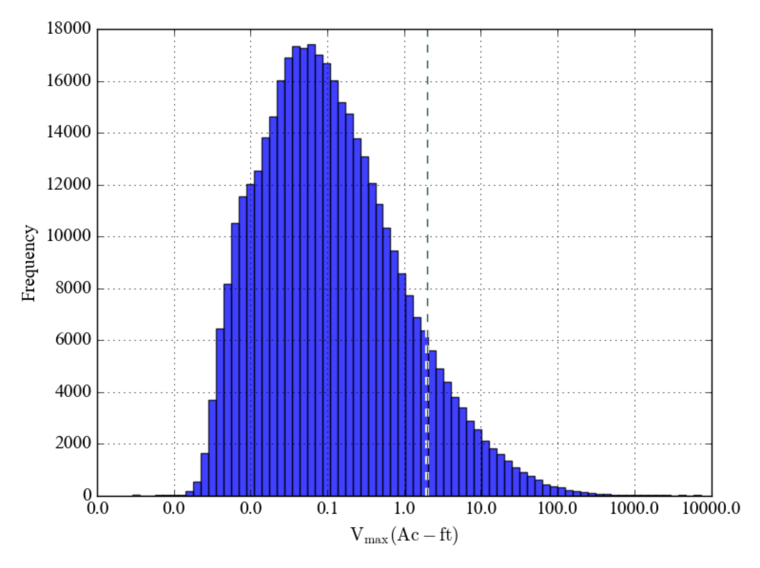
35	0.11	2115	75.69
43	0.12	2502	96.84
72	0.13	3150	121.86

Results: General Statistics







- $\overline{H_{max}} \cong 0.3$ m.
- Heavy-tail.
- Positively skewed .
- Possible power-law dist.
- Some artifacts left (large H_{max}).

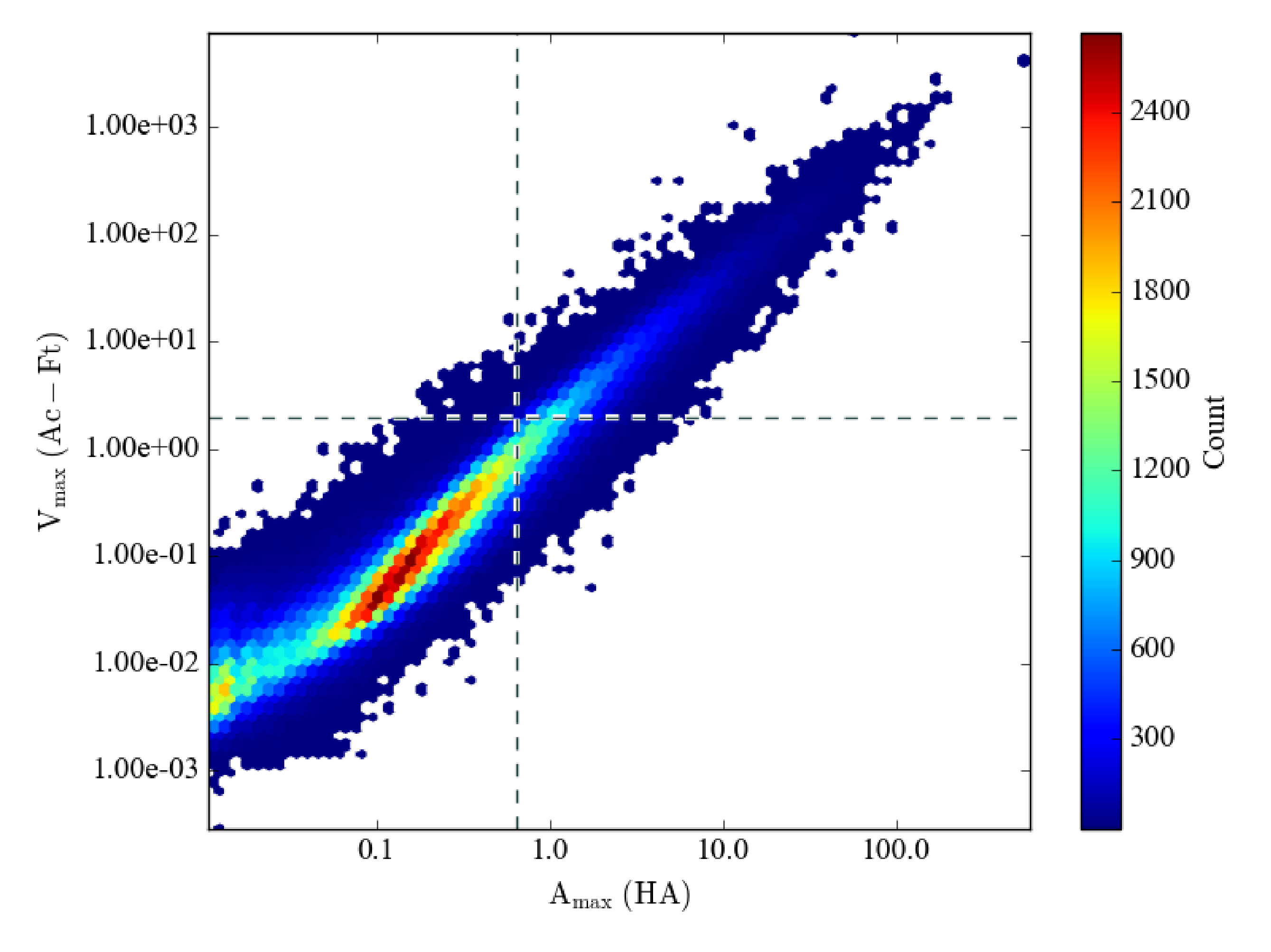
- $\overline{A_{max}} \cong 0.7$ Ha.
- Heavy-tail.
- Positively skewed.
- Biomodal dist?
- Some artifacts left (large A_{max}).

- $\overline{V_{max}} \cong 2$ Ac-ft.
- Heavy-tail.
- Positively skewed.
- Gamma dist.?
- Some artifacts left (large V_{max}).

Constrained to maximum depths > 0.1 meters (LiDAR vertical error of ~ 0.15 m)

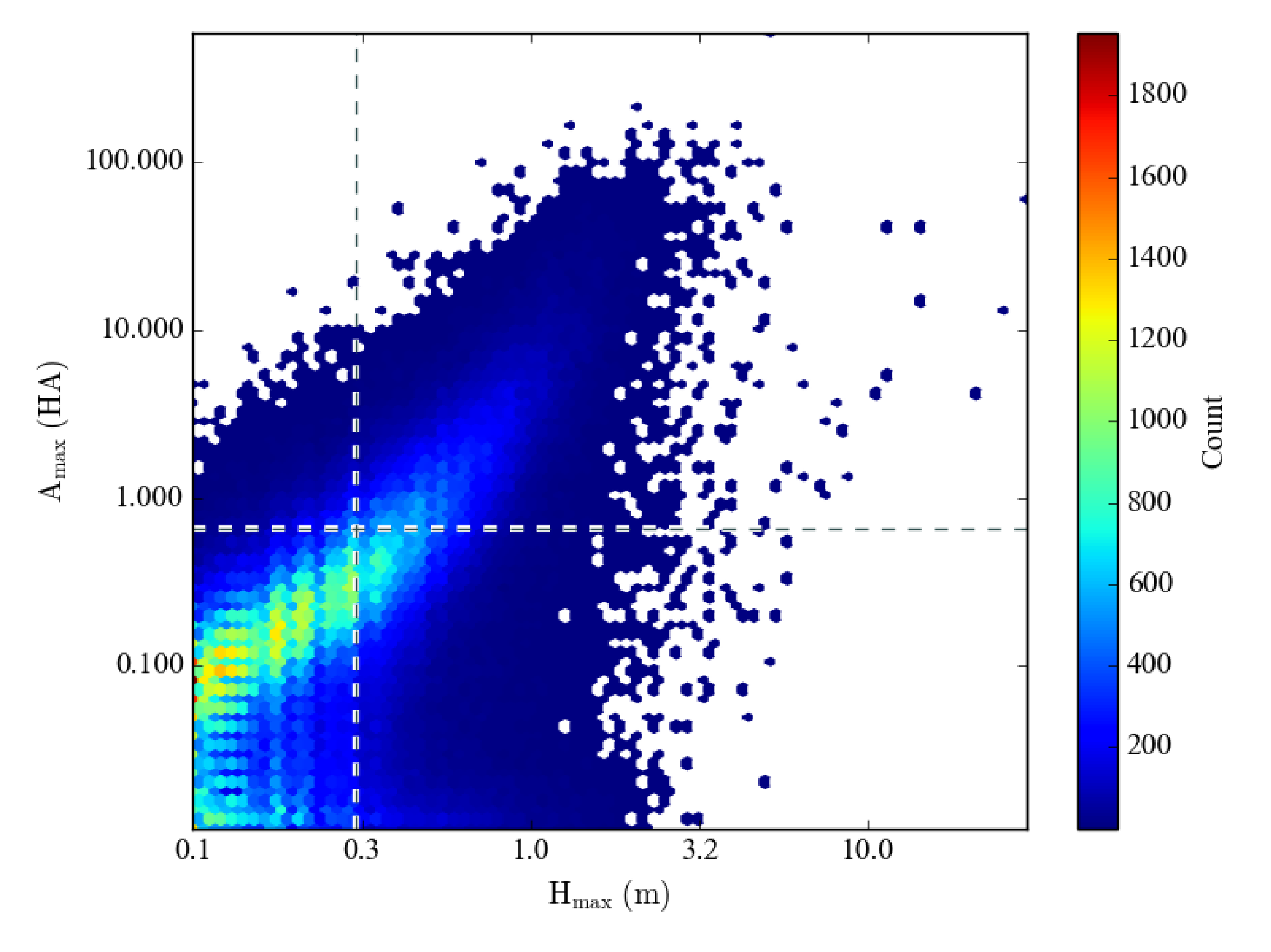
Results: Maximum Volume-Area

- Strong power-law relationship
- Clustered in a narrow range between 0.075 and 3 HA and 0.01 and 7500 Ac-ft
- Two possible distributions/clusters
- Significant variance



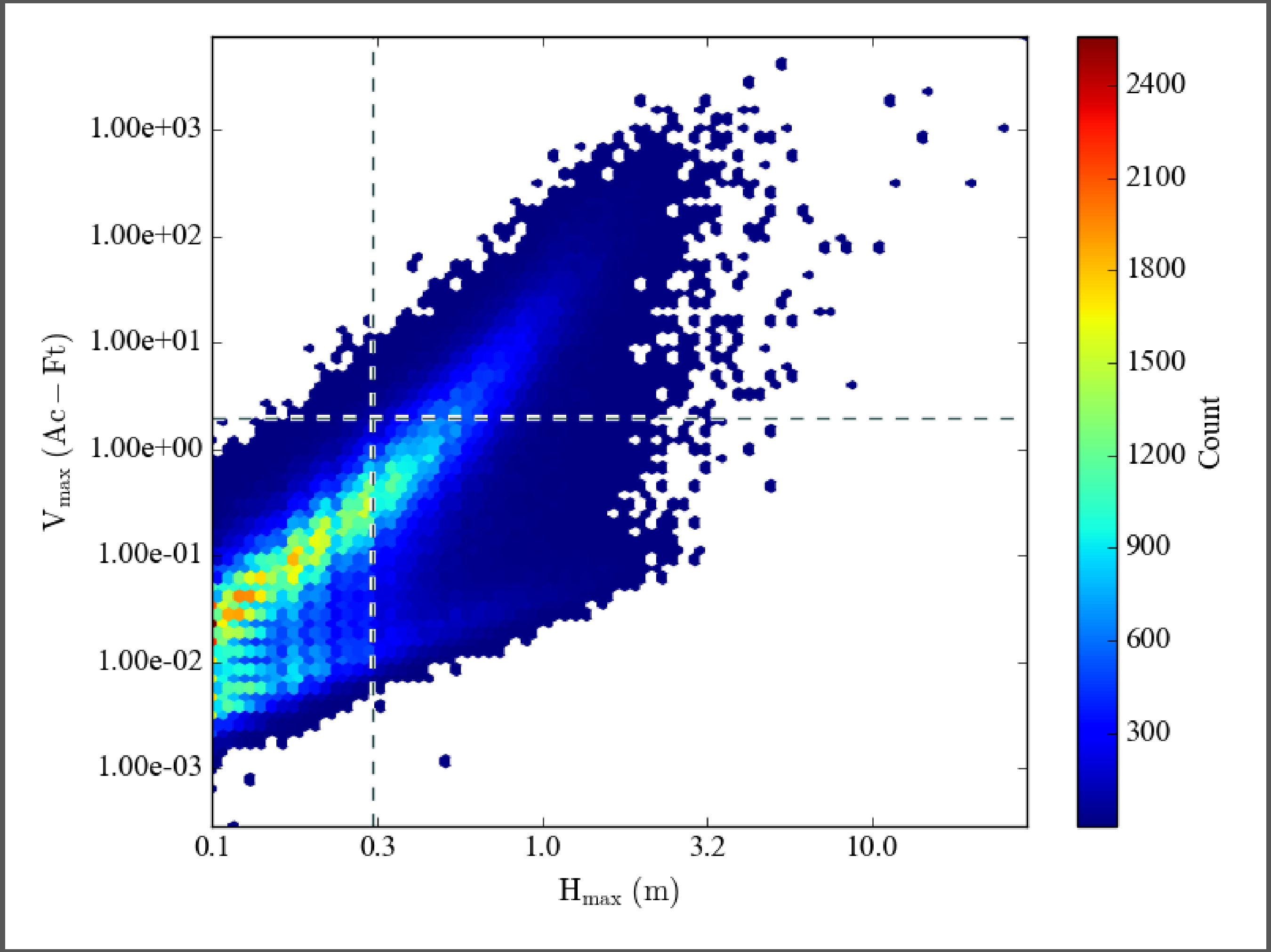
Results: Maximum Depth-Area

- Much greater variance
- Two possible distributions
- Strong clustering above 0.1 HA with majority between 0.05 and 1 HA, and 0.1 and 0.5 m
- Potential LiDAR/DEM Artifacts

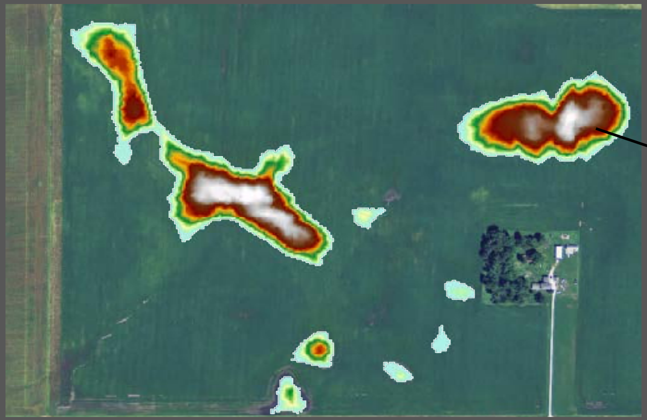


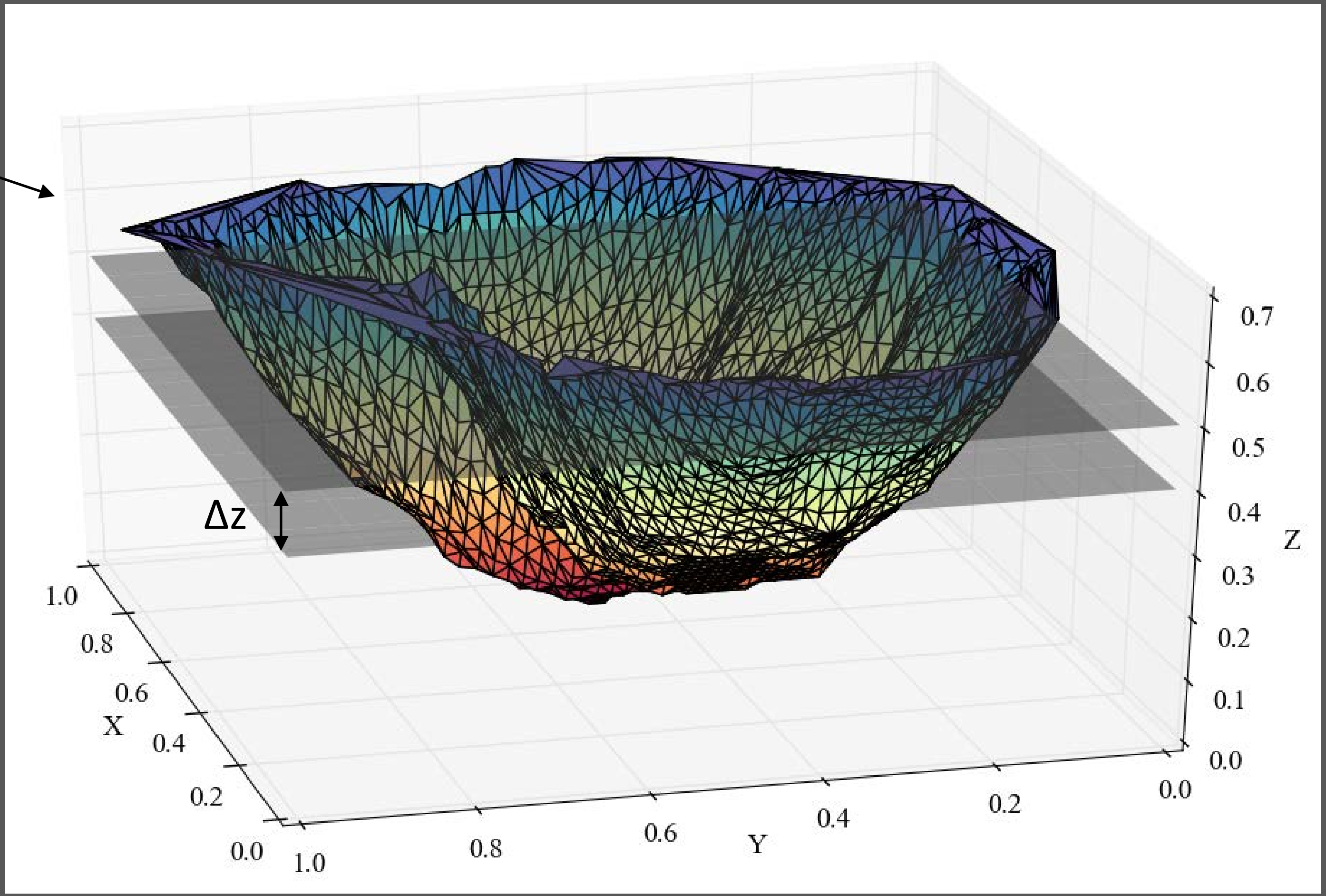
Results: Maximum Depth-Volume

- Two possible distributions
- Clustering between 0.05 and 1 Ac-ft, and 0.1 and 0.5 m
- Relatively strong power-law relationship
- Some artifacts are present



Error Analysis: Triangulated Surfaces

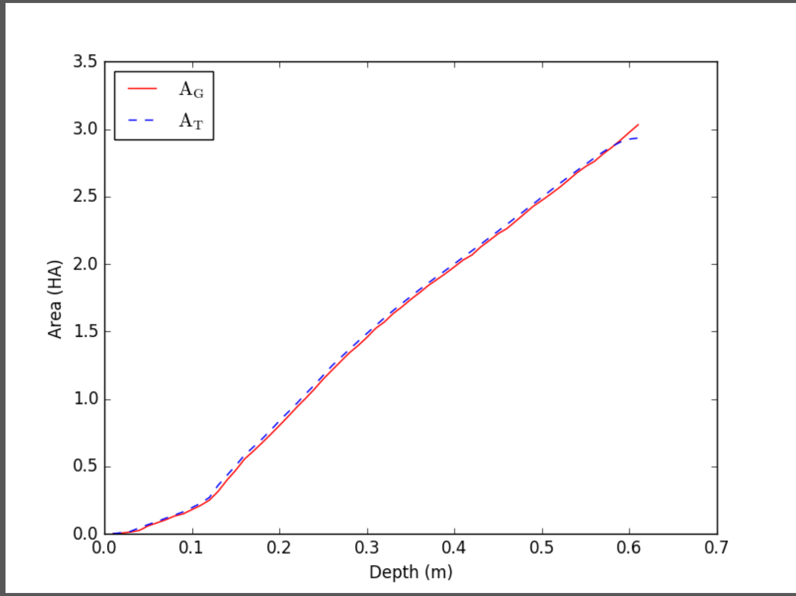




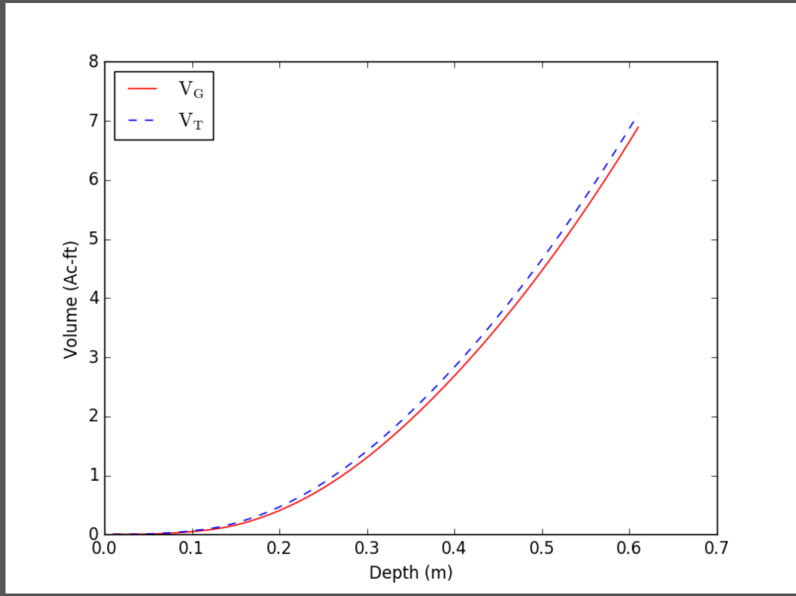
- Uses a triangulated, not gridded, surface with plane slicing
- Analogous to trapezoidal integration over a 3D surface
- Presumably more accurate than our method, but by how much?
- ArcGIS 3D Analyst uses this method for volume-area analysis

Error Analysis: Results

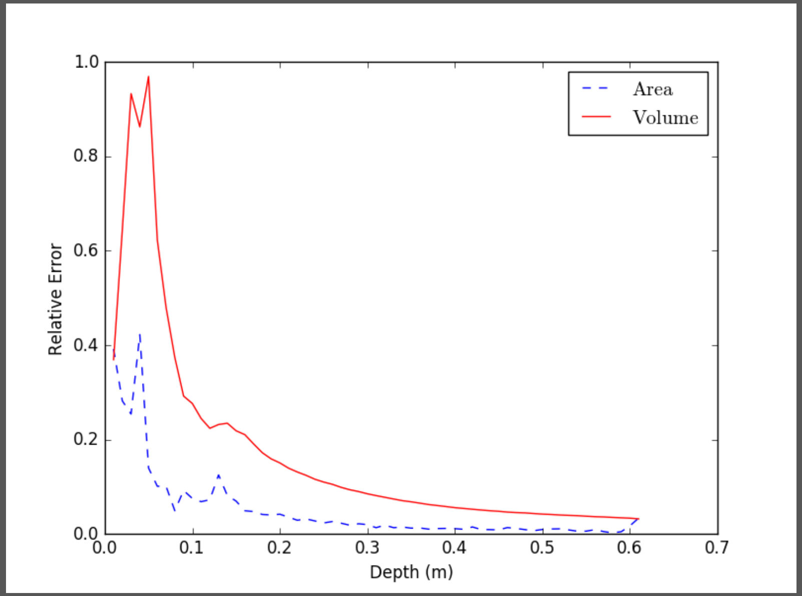
Area

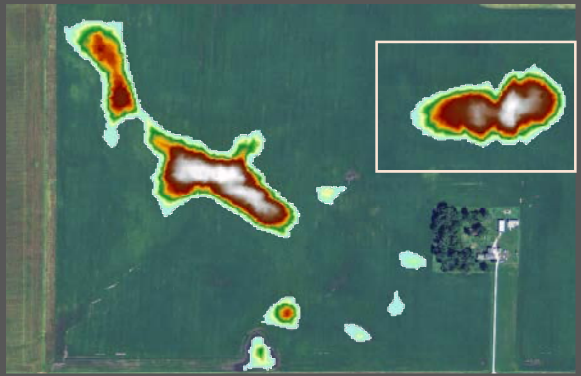


Volume



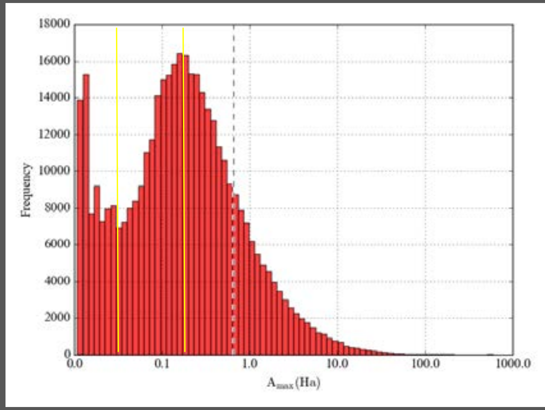
Relative Error

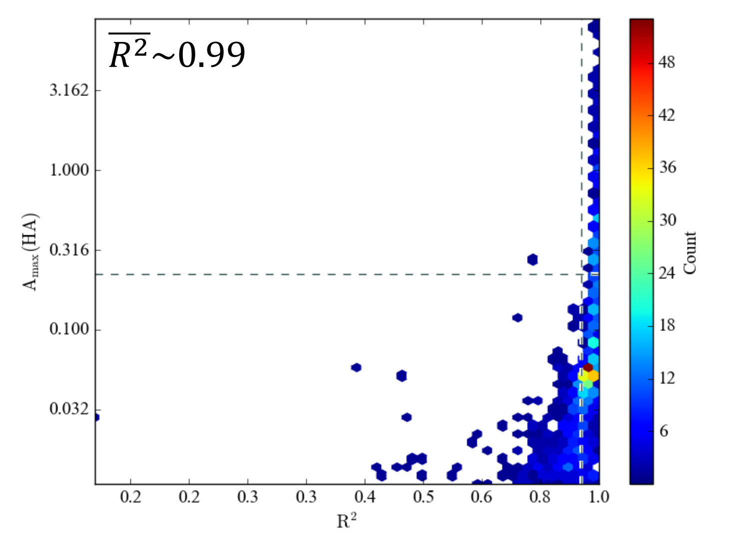


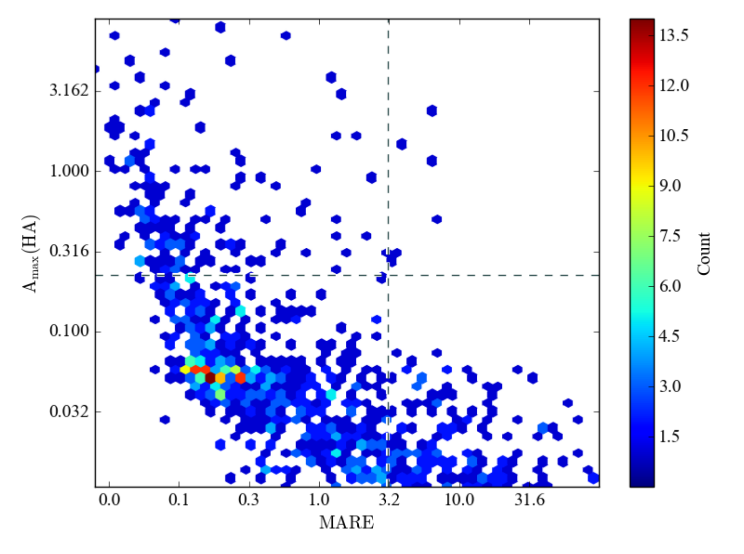


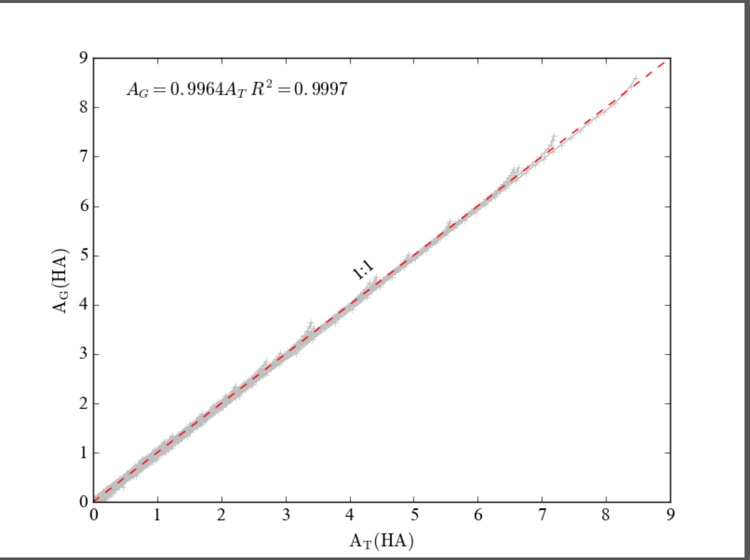
Error Analysis: Results

- 1000 Randomly selected depressions.
- 3 Area groupings defined from the ‘natural’ breaks of A_{max}.



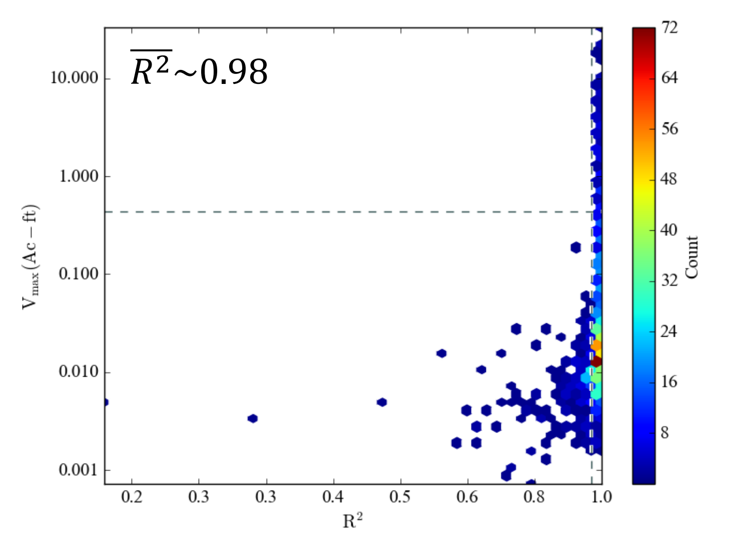


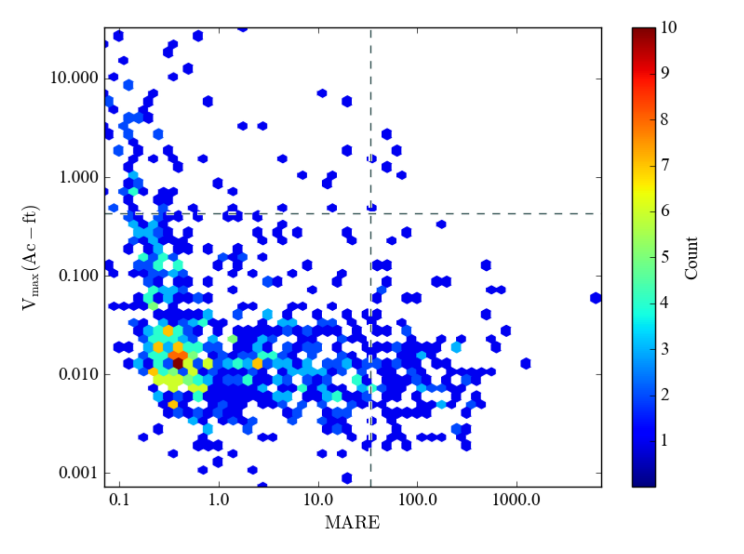


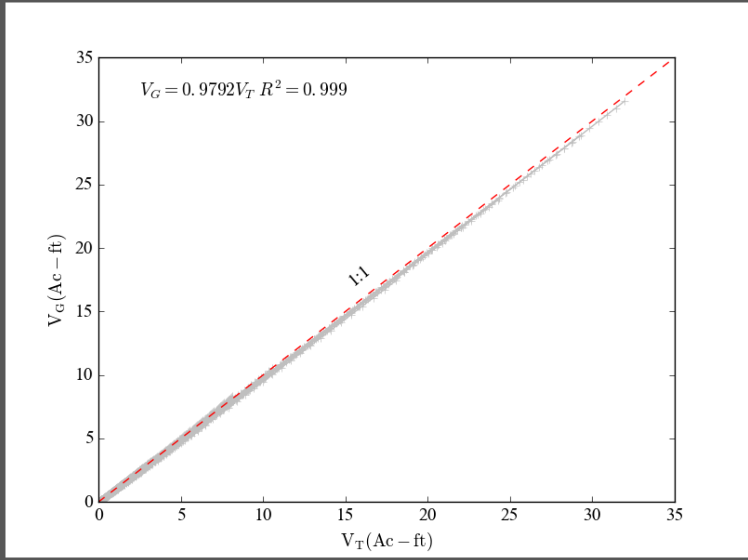


Error Analysis: Results

- Larger depressions → smaller error.
- Our method seems to work best with V > 0.05 Ac-ft.
- Slightly under-predicts V > 20 Ac-ft.



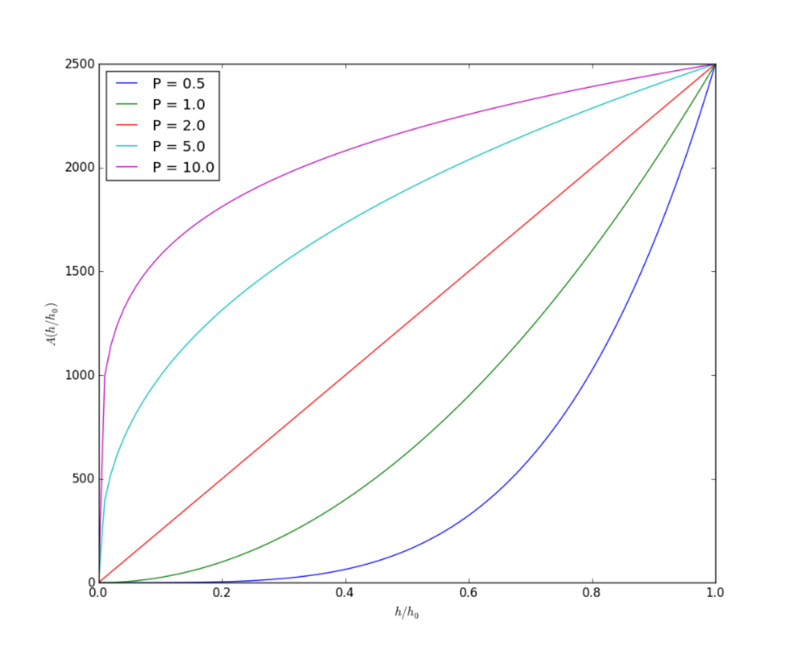


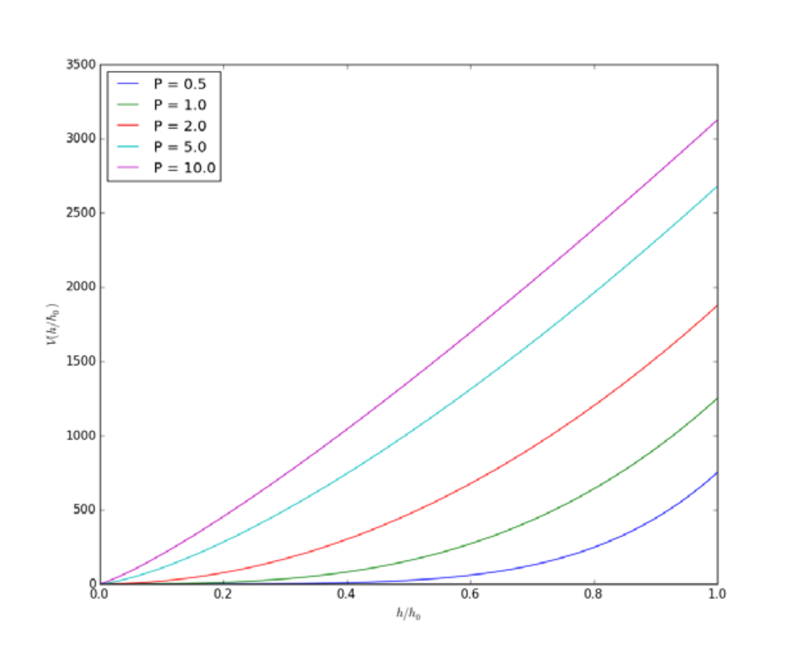


Power-law Models

Hayashi-van der Kamp (2000) model:

$$A(h) = A_0 \left(\frac{h}{h_0} \right)^{2/P} \qquad V(h) = \left(\frac{A_0}{1 + 2/P} \right) \frac{h^{(1+2/P)}}{h_0^{2/P}}$$

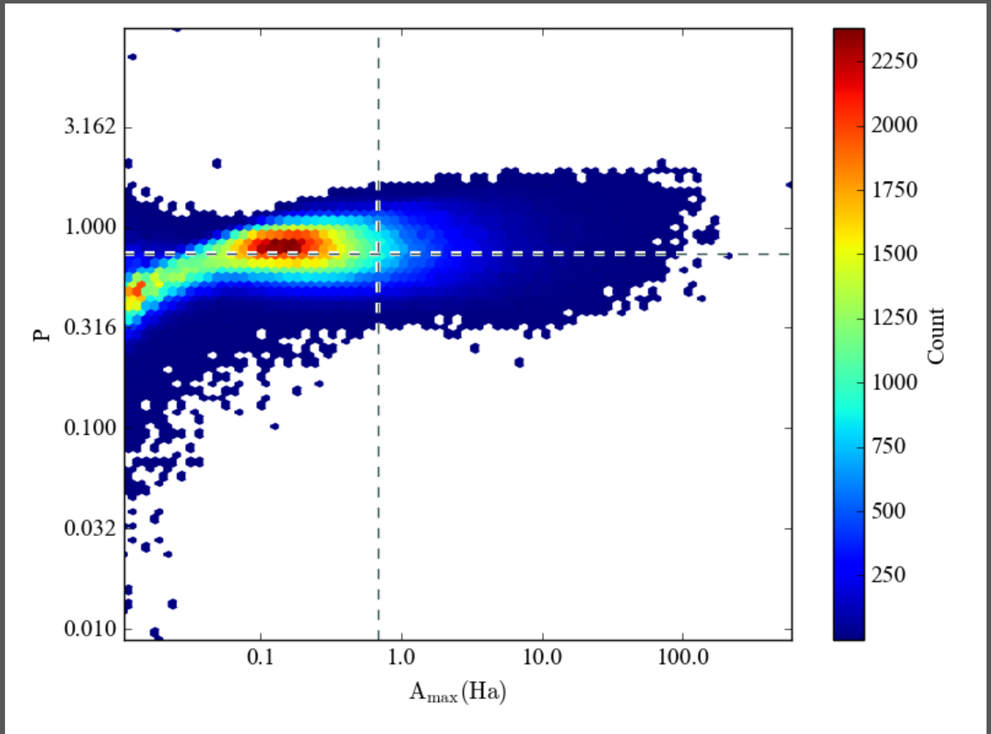


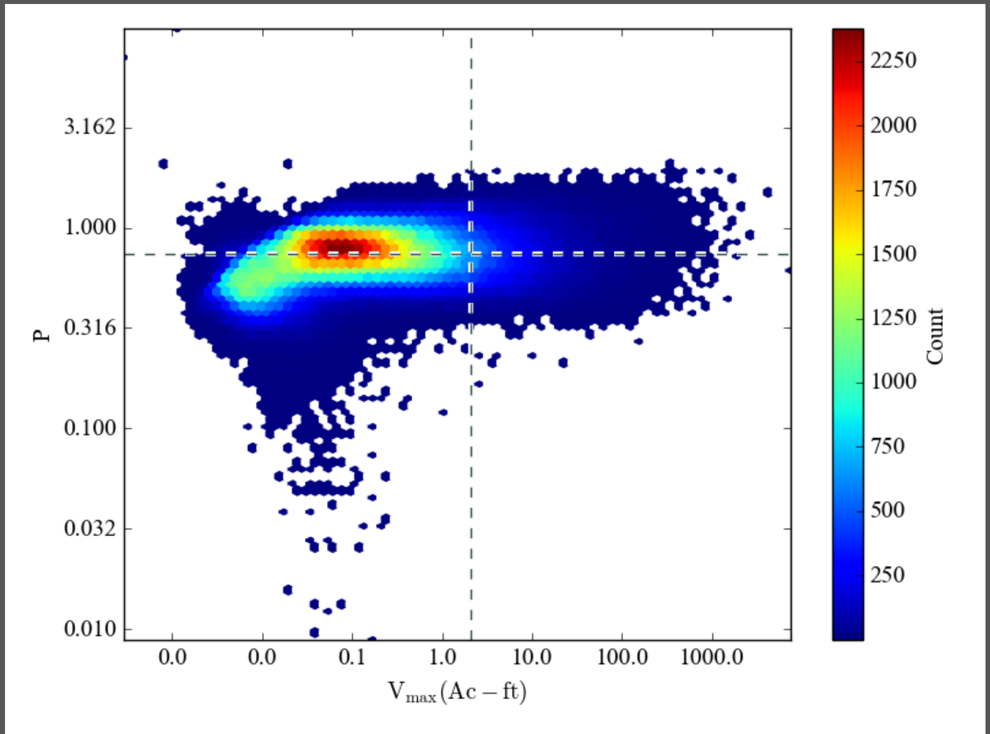


$$P \rightarrow \begin{cases} < 1: \text{Concave} \\ > 1: \text{Convex} \end{cases}$$

$$A_0 \rightarrow A_{max}$$

Power-law Models

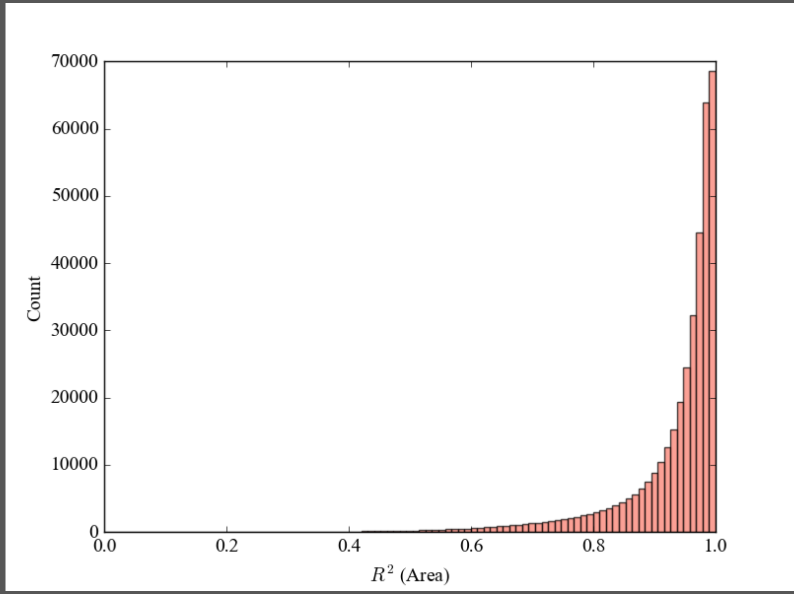




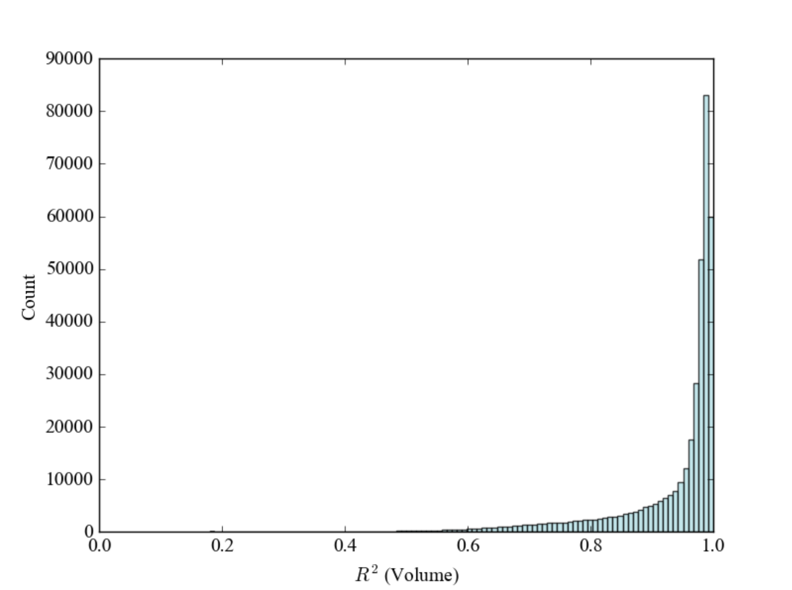
- Increasing convexity with increasing area and volume up to A_{max} ~ 1 Ha
- Also observed by Hayashi and van der Kamp (2000)

$$P \rightarrow \begin{cases} <1: \text{Concave} \\ >1: \text{Convex} \end{cases}$$

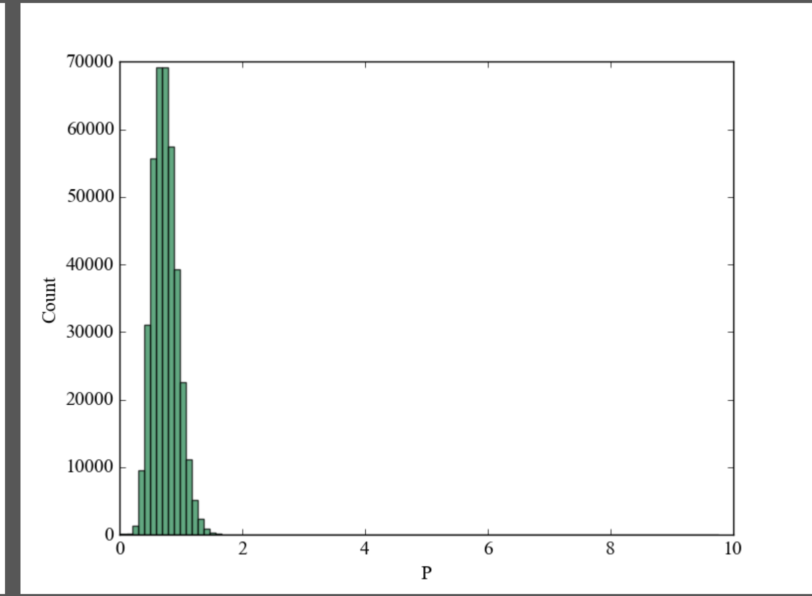
Power-law Models



Area



Volume



P

- Most depressions reasonably fit the Hayashi-van der Kamp model (i.e. they are well described by a power-law relationship)
- Slight tendency for fit to increase with increasing A_{max} and V_{max}
- P ranges from 0.01 to ~10 with a mean and median of ~0.72 (~Normally distributed) indicating that most depressions are slightly concave in shape

Next Steps

Geodatabase of depressional morphology for the DML-IA will be made publically available (likely 2018).

Tool will be converted into an ArcGIS toolbox and will be publically available for download (likely 2018).

Simulations of surface runoff processes to assess the influence of depressional storage on hydrograph development on selected HUC 12 watersheds planned (GSSHA 2D Watershed Model).

Acknowledgements

Samuel McDeid, Iowa State University

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Brian Gelder, Iowa State University

U.S. EPA Region 7

Soil and Water Conservation Society

Iowa Department of Natural Resources

References

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